Goddard Space Flight Center

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Characterization of the Twelve Channel 100/140 Micron Optical Fiber, Ribbon Cable and MTP Array Connector Assembly for Space Flight Environments.

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Abstract

Presented here is the second set of testing conducted by the Technology Validation Laboratory for Photonics at NASA Goddard Space Flight Center on the 12 optical fiber ribbon cable with MTP array connector for space flight environments. In the first set of testing the commercial 62.5/125 cable assembly was characterized using space flight parameters (published in SPIE Vol. 3440).[1] The testing showed that the cable assembly would survive a typical space flight mission with the exception of a vacuum environment. Two enhancements were conducted to the existing technology to better suit the vacuum environment as well as the existing optoelectronics and increase the reliability of the assembly during vibration. The MTP assembly characterized here has a 100/140 optical commercial fiber and non outgassing connector and cable components. The characterization for this enhanced fiber optic cable assembly involved vibration, thermal and radiation testing. The data and results of this characterization study are presented which include optical in-situ testing.

Background

This is a follow up paper to the publication entitled "Twelve channel optical fiber connector assembly: from commercial off the shelf to space flight use". SPIE vol. 3440. In the first paper the commercial version of the MTP and ribbon cable assembly was investigated and suggestions were made to enhance its performance. This paper investigates the results of those enhancements through performance testing.

The twelve fiber ribbon cable with MTP array connector was selected to support the cable harnessing for the Spaceborne Fiber Optic Data Bus (SFODB) on space flight missions selected to utilize this communications system. The ribbon cable itself was selected with a Kynar jacket and manufactured by W.L. Gore. The MTP connector with the two enhancements mentioned above was manufactured by USCONEC. The terminations were fabricated by USCONEC using space flight procedures as adjusted to the array connectors and with compliance to NASA-STD-8739.5.

Originally a materials analysis was conducted on the commercially available 62.5/125 micron ribbon cable and MTP array connector assembly to determine which materials would be suitable for a vacuum environment. The analysis led to the enhancements of the boot and ferrule boot components of the connector.

A second enhancement to increase the reliability of the connection link during vibration was made to the commercially available cable/connector assembly. The ferrule size was changed from the 125 micron hole size to the 140 micron hole size to accommodate the 100/140 micron optical fiber that was preferred by the optoelectronics provider for the SFODB system.

The types of testing chosen for this study was designed to bring out known failure mechanisms of the cable assembly system and this sequence of environmental testing was developed based on previous research.[2-4] This characterization study was conducted in three sections 1) vibration characterization, 2) thermal characterization and 3) radiation characterization, respectively. The sequence of testing was conducted in this order with visual inspections before and after each test and optical performance monitoring conducted in-situ for some channels based on available equipment.

Experimental Summary

Three mated pair connector/cable assemblies were tested of length 5.24 m and the sequence and summary of testing is in table 1.

Table 1: Cable Channels monitored during testing

Test	Cable Designation	Channel Optically Monitored	Channel Visual Inspection
Vibration	DUTA	1,3,5,6,8,10,12	All
	DUTB	1,3,5,6,8,10,12	All
	DUTC	1,3,5,6,8,10,12	All
Thermal	DUTA	1, 5, 8, 12	All
	DUTB	1, 5, 12	All
	DUTC	1,3,5,6,8,10,12	All
Radiation	DUTA	12	All
	DUTB	12	All

A visual and optical performance verification was performed prior to any environmental testing on all Device Under Test (DUT) cable sets and testing fan out cables. Three mated pairs of cables were tested during vibration and thermal and two of the three cables were testing during radiation characterization.

Vibration Characterization

The main purpose of the vibration testing was to verify that the MTP assemblies would in fact survive typical launch vehicle conditions. In addition however, an interrupt test was conducted to verify whether the connector assemblies could be in operation during a launch.

The MTP ribbon connector assemblies were tested in three dimensions x, y, and z. The same fixturing and axis conventions were used as were used during the research conducted in 1998 [1]. The HP81552SM 1310 nm laser source was used for in-situ testing, coupled into a 1 X 8 100/140 micron diameter optical fiber coupler. The coupler mated to the input fan out cable and then into lead cables that mated to the DUT mated pair that was attached to the vibration shaker fixturing. Figure 1A shows the z axis mounting of the MTP assemblies on the vibration shaker and Figure 1B shows the entire set up for the vibration characterization.

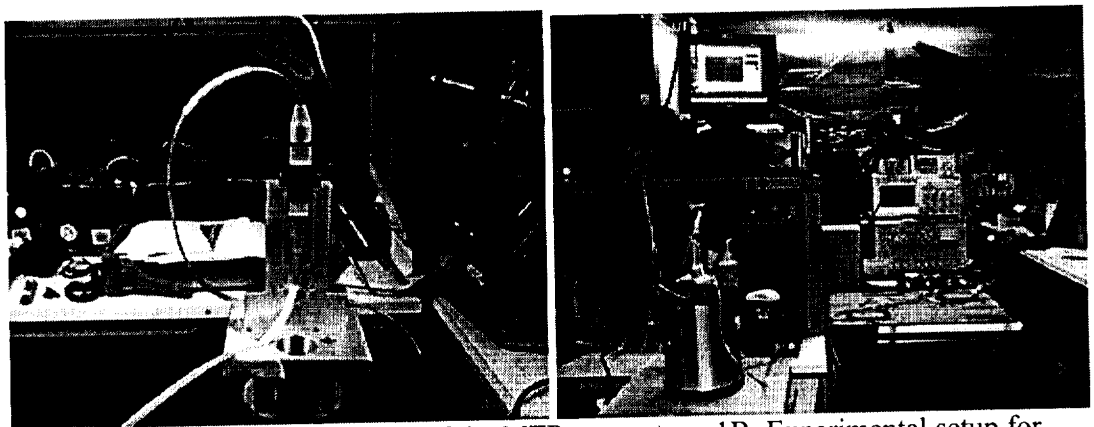


Figure 1, 1A: Z axis fixturing of the MTP connectors, 1B: Experimental setup for vibration characterization of MTP assemblies.

During axis test, channel six was monitored with an optical to electrical converter and oscilloscope in order to detect interrupts occurring larger than a 25 micro second sampling rate. The remaining channels were monitored via the HP8166 multichannel optical power multimeter.

The parameters used for this testing are summarized in Table 2.

Table 2: Vibration profile for MTP vibration testing

Frequency (Hz)	**Protoflight Level**
20	**.052 g^2/Hz**
20-50	**+6 dB/octave**
50-800	**.32 g^2/Hz**
800-2000	**-6 dB/octave**
2000	**.052 g^2/Hz**
Overall	**20.0 grms**

The duration for testing at each axis position was three minutes and the axis sequence of testing was x, y, z respectively. After each axis test was completed, all optical fiber end faces were visually inspected for damage. Optical data was collected during the testing and recorded via lap top computers to excel spreadsheet files using custom written Labview data acquisition programs.

Vibration Characterization Results

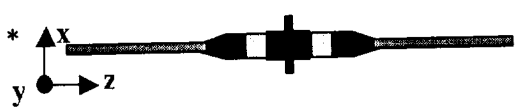
For each mated pair cable assembly under test, two types of optical in-situ testing was conducted. For each DUT, six channels were monitored actively with the HP8166 for transmission interruptions or "static" losses that occur slowly while testing. One channel, channel six, of each mated pair was monitored with an optical to electrical (O/E) converter and digital oscilloscope to measure intermittent transmission losses. A 25 microsec sampling rate was the shortest sampling rate we attained for the in-situ "dynamic" monitoring of channel six. Again, the point was to monitor for events that signified a drop out of optical power transmission (or transient) through the mated pair. For each axis, this data was collected for each mated pair. The laser source was monitored during data acquisition from the HP8166 such that the variation of the laser power was subtracted from variations in transmission as a result of the vibration. Concluding each axis test, a visual inspection of the MTP endface was performed and as a result no damage was detected as compared to the initial state of each connector endface recorded prior to testing.

In Table 3 the data is summarized for each cable and axis test, in the order the tests were conducted. The data presented is for channel six of each cable set tested using a 25 microsec sampling rate.

Table 3: Vibration induced events (dynamic losses) for channel six of each cable Assembly, mated pair for each axis

DUT Test Set	Vibration Test Axis*	Loss events registering below noise level
A	X	Less than 1.2 dB
A	Y	Less than 0.1 dB
A	Z	Less than 0.1 dB
B	X	Less than 0.1 dB
B	Y	Less than 0.1 dB
B	Z	Less than 0.1 dB
C	X	Less than 0.1 dB
C	Y	Less than 0.1 dB
C	Z	Less than 0.2 dB

*



With the exception of DUT A during the x axis orientation vibration test, most of the event losses were around or less than 0.1 dB and the events lasted no more than the sample rate of 25 microsec. Figure 2 is an example of the data summarized in Table 3. In this example the mated pair set is DUT A and the test is along the y axis for detecting negative transients below the noise. The test duration was 3 minutes or 180 seconds and data just before and after the vibration test for a few seconds is recorded as well.

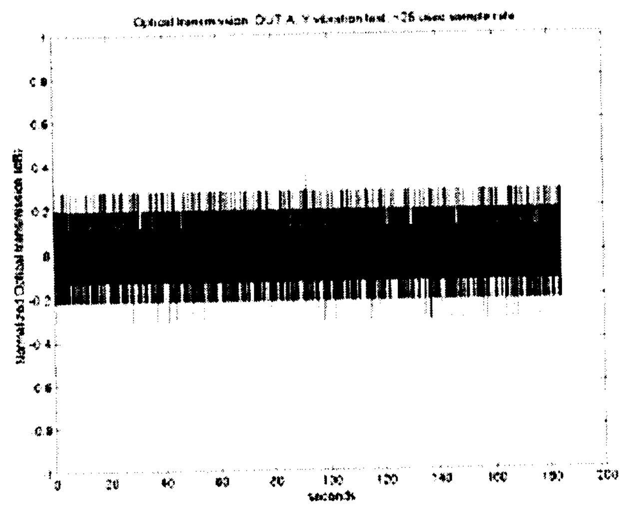


Figure 2: Optical transmission, normalized (dB) vs. time in seconds for the y axis vibration test of DUT A using a 25 micro second sampling rate.

In Table 4, the vibration data is summarized for the remaining channels that were monitored optically during testing for "static" losses. The data summarized in Table 4 represents the slow losses measured at approximately a 5 sec sample rate. These are referred to as the static losses because they are slow changes in transmission performance that occur as a result of vibration induced effects. The source noise, which was never greater than .03 dB max at any given time, was subtracted out of the final data summary.

Table 4: Summary of MTP vibration data (static losses) on channels 1,3,5,8,10, & 12.

Cable Assembly (DUT)	Axis Test	Transmission Loss Recorded
A	X	Less than .08 dB
A	Y	Less than .10 dB
A	Z	Less than .11 dB
B	X	Less than .13 dB
B	Y	Less than .35 dB
B	Z	Less than .03 dB
C	X	Less than .15 dB
C	Y	Less than .40 dB
C	Z	Less than .28 dB

Figures 3 through 11 display the data summarized above in Table 4 for each test. These graphs represent the "static" losses as a result of vibration testing during the three minute test. In some cases it can be noted that the performance during the static or slower monitoring of the transmission is similar to the channel six dynamic high speed tests summarized in Table 3 and in other cases some of the monitored channels show a shift in alignment of the MTP interconnection during the testing. Some cable data shows some channels shift into a gain transmission situation while other cables show decrease in optical transmission. This can be seen in Figure 6 during the y vibration testing of DUT B and could be due to a twisting along the z direction. In Figure 7 the z axis testing of DUT

B there seems to be a gain over the duration of the testing. This could indicate a movement along the x axis that could cause better alignment along this axis. Another cause for this would be if the connectors are not actually physically touching as they are supposed to do when inside the connecter adapter, they could be moving uniformly in the z direction and forcing a better physical contact between the two interfaces of each connector end. In all cases the losses never exceeded 0.5 dB for any of the channels tested and none of the optical fiber interfaces were damaged as a result of the vibration launch conditions used in this experiment. This fact was verified through visual inspection.

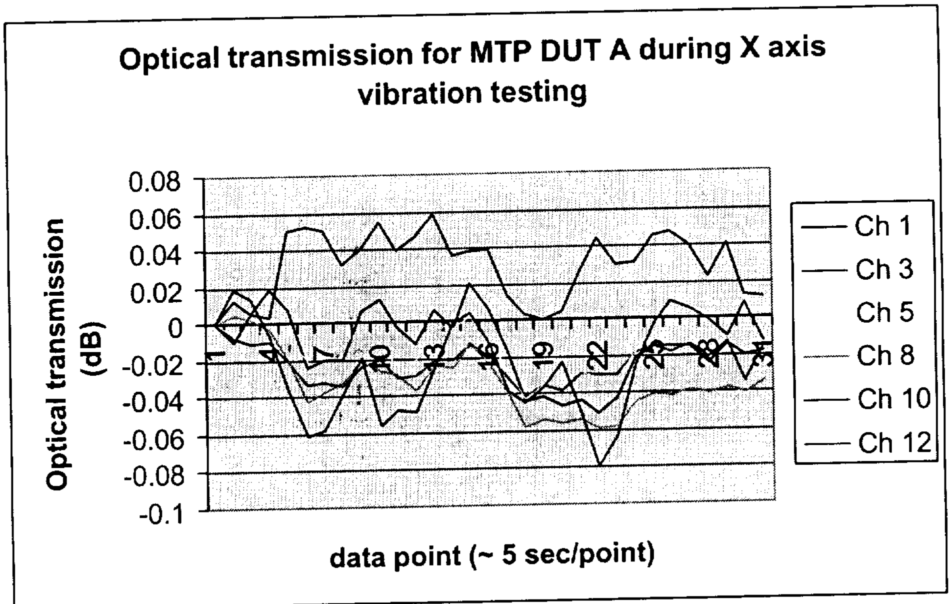


Figure 3: In-situ optical data of DUT A during X vibration testing for all channels monitored: 1,2,3,5,8,10 and 12.

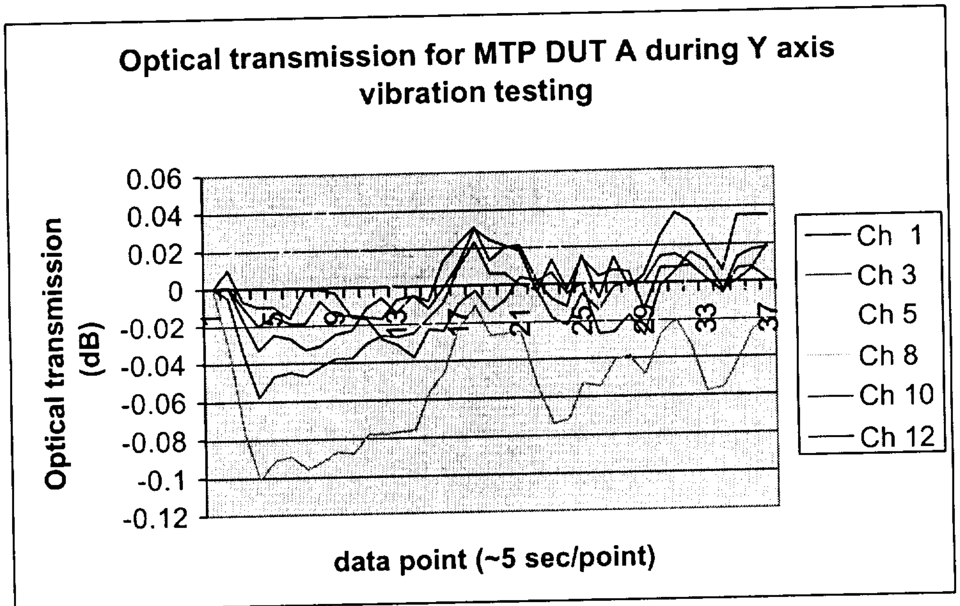


Figure 4: In-situ optical data of DUT A during Y vibration testing for all channels monitored 1,2,3,5,8,10 and 12.

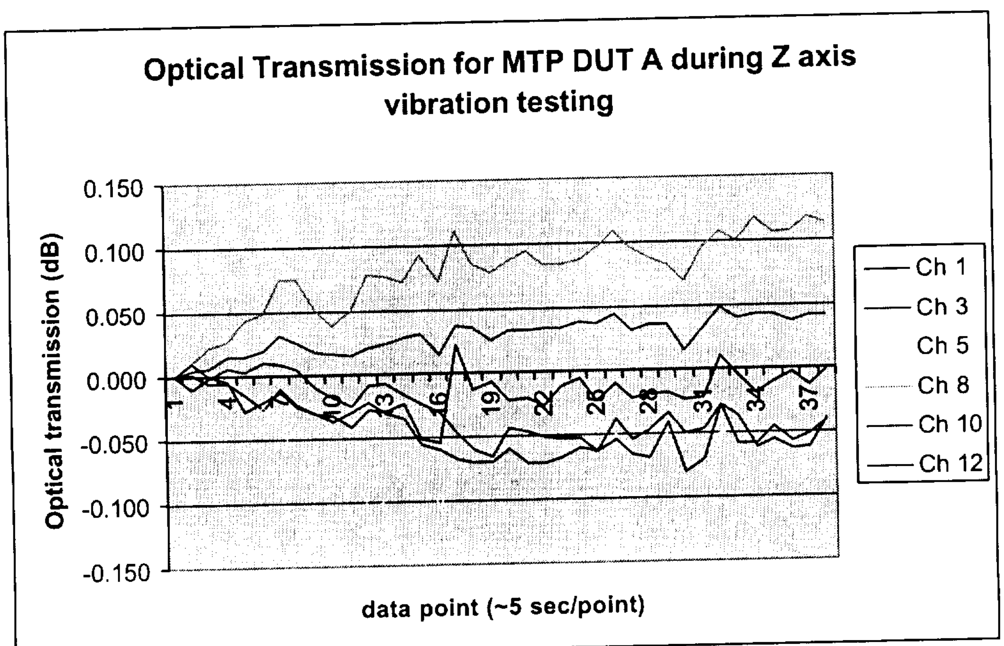


Figure 5: In-situ optical data of DUT A during Z vibration testing for all channels monitored 1,2,3,5,8,10 and 12.

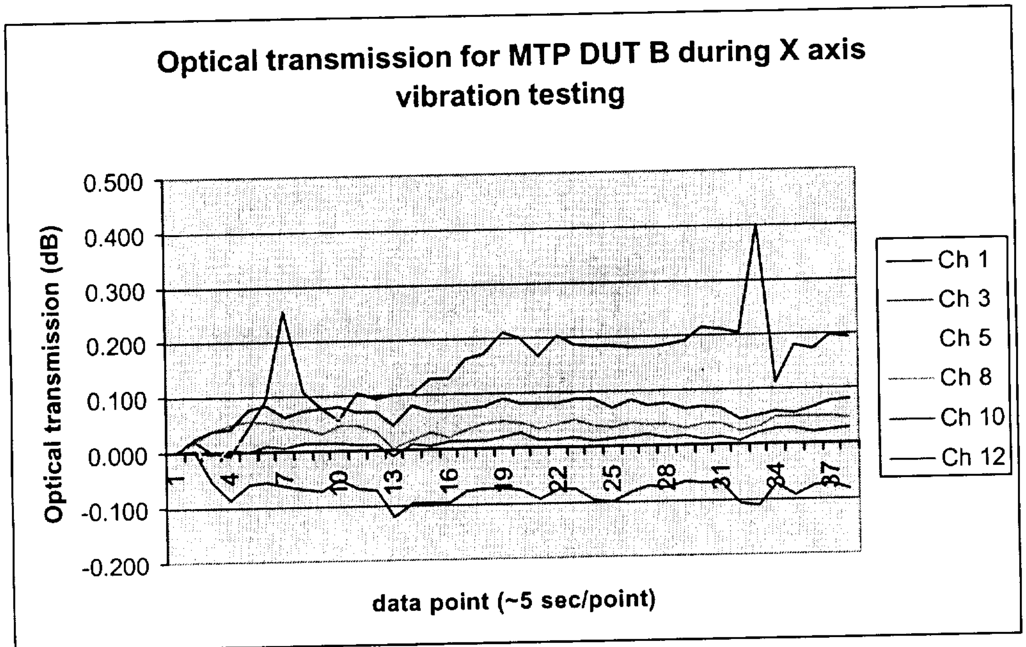


Figure 6: In-situ optical data of DUT B during X vibration testing for all channels monitored 1,2,3,5,8,10 and 12.

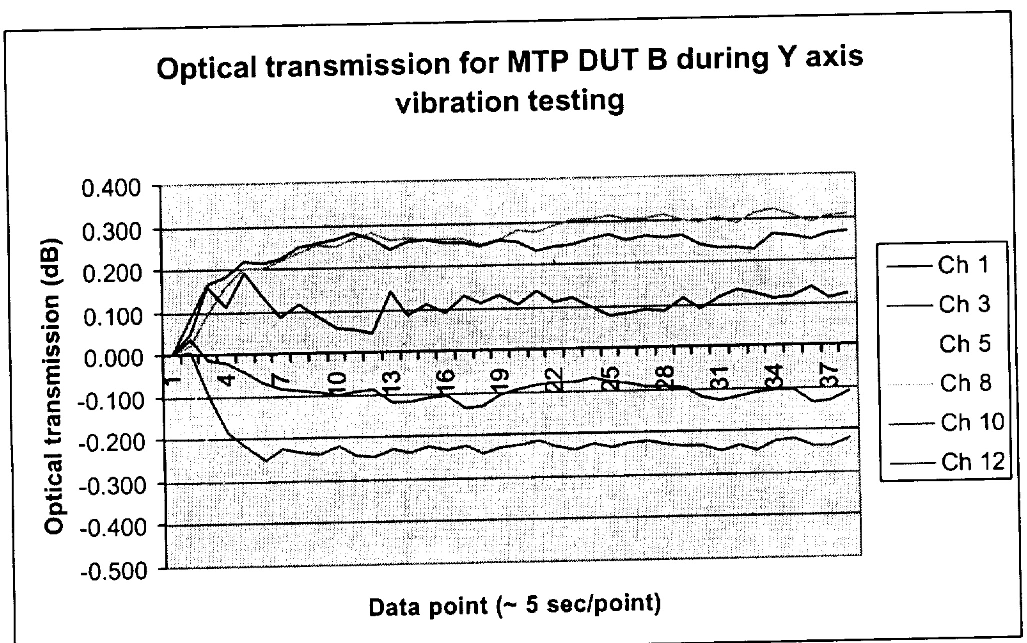


Figure 7: In-situ optical data of DUT B during Y vibration testing for all channels monitored 1,2,3,5,8,10 and 12.

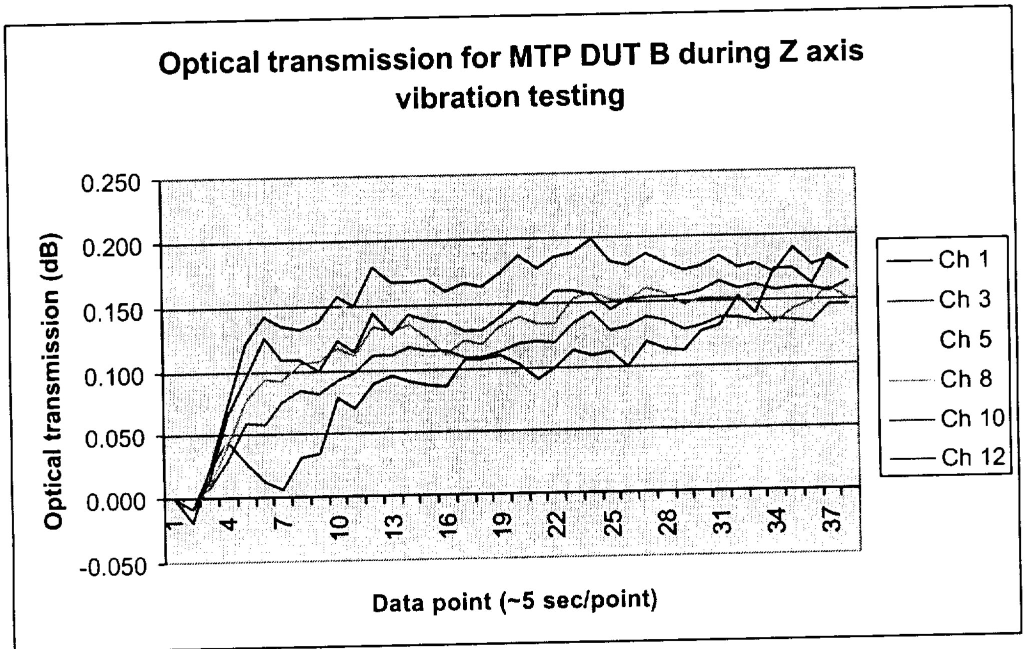


Figure 8: In-situ optical data of DUT B during Z vibration testing for all channels monitored 1,2,3,5,8,10 and 12.

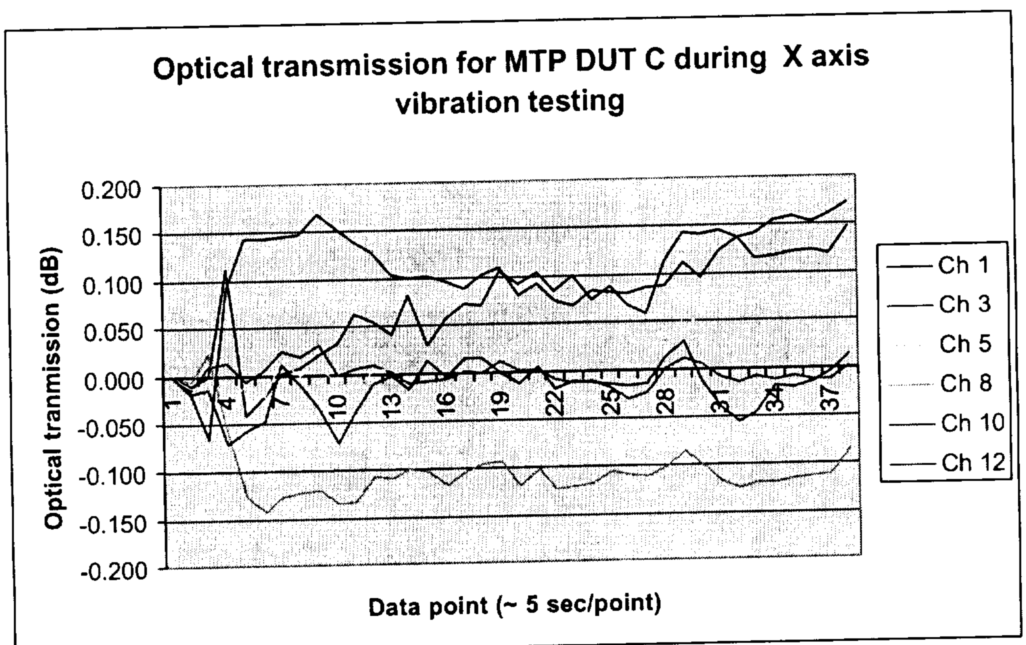


Figure 9: In-situ optical data of DUT C during X vibration testing for all channels monitored 1,2,3,5,8,10 and 12.

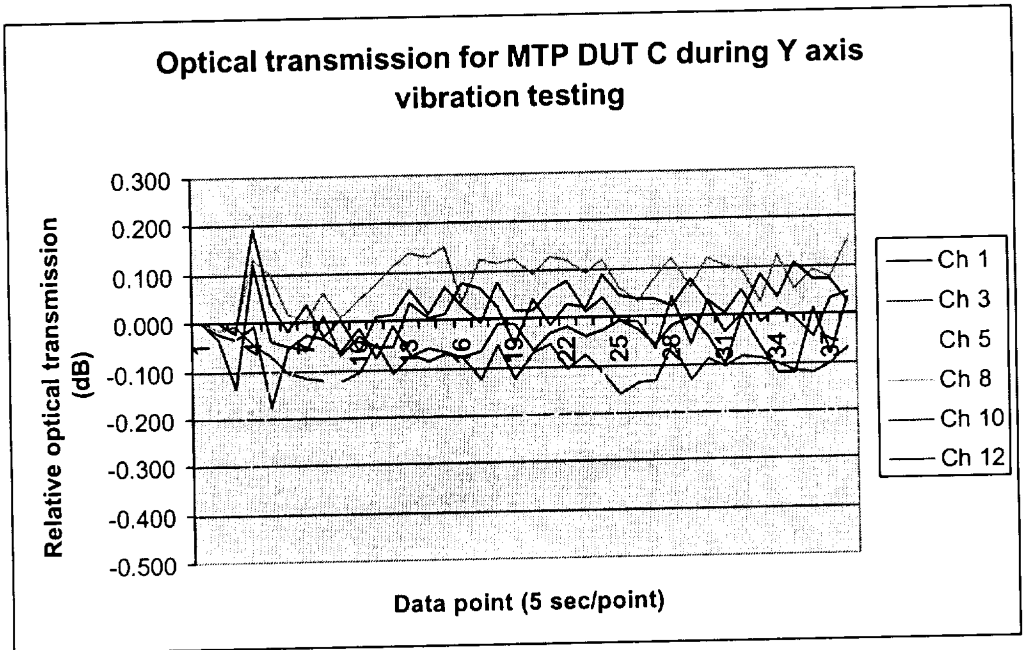


Figure 10: In-situ optical data of DUT C during Y vibration testing for all channels monitored 1,2,3,5,8,10 and 12.

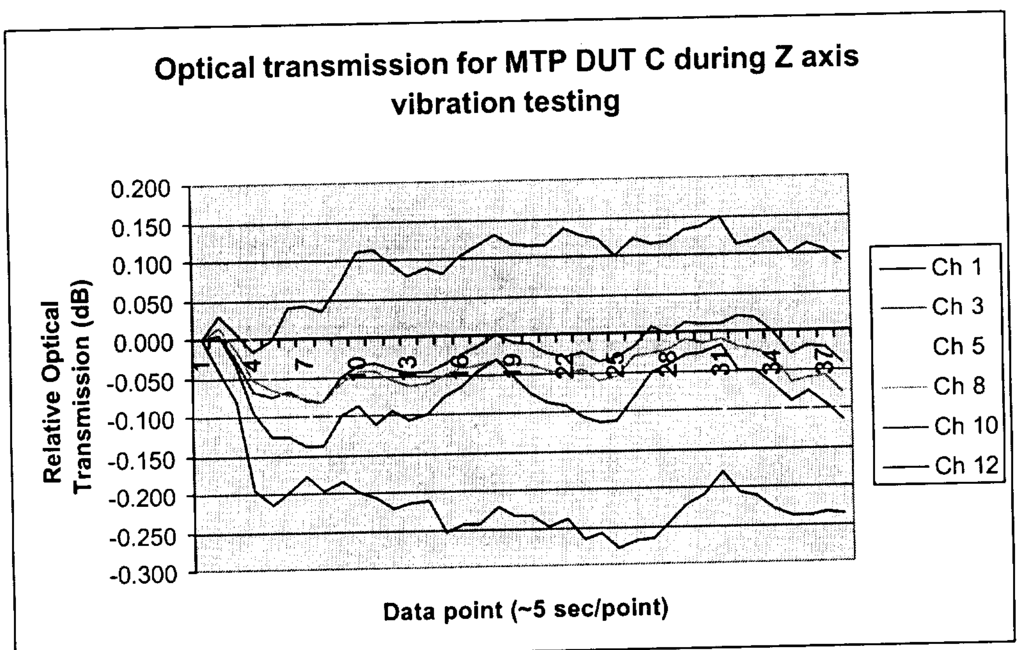


Figure 11: In-situ optical data of DUT C during Z vibration testing for all channels monitored 1,2,3,5,8,10 and 12.

Thermal Characterization

The MTP DUTs (mated pairs) were placed inside the thermal chamber with the other ends just outside the chamber and mated to the fan out cables that connect the MTP connector to individual channels on the HP8166. The bulk of the 5.24 m was inside the chamber. As in the experimental set up for the vibration test, the same laser source was used. The environmental parameters were 38 cycles for DUT A and B, and 18 cycles for DUT C, from -20° C to +85 °C, with a ramp rate of 1 °C/min and dwell times at the extremes of 25 minutes. The source light was coupled into eight optical fibers and then connected to the MTP fan out cables which in turn connected to the test set (DUT) mated pair that was inside the thermal chamber. DUT A and DUT B were tested using the same pair of fan out cables and were monitored for 38 thermal cycles. DUT C was monitored for a total of 18 thermal cycles.

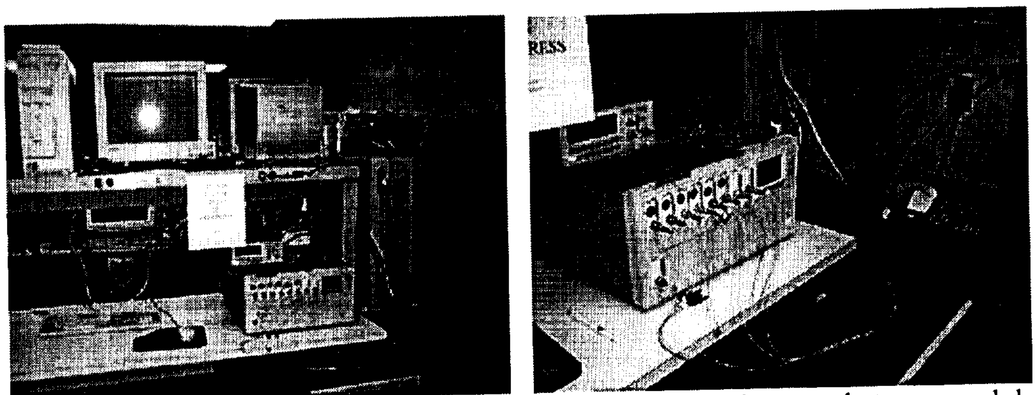


Figure 12: Two views of the optical monitoring experimental set up that was used during thermal cycling testing.

Thermal Results:

The data and summary of results are presented in Table 5. The source power drift was subtracted from the data such that only changes as a result of thermal testing would be presented. In the summary in Table 5, the data is described in column three by the maximum amount of thermally induced power changes within a single optical cycle. In the last column the data is described but the total amount of thermally induced power changes during testing or the difference between the maximum measured optical transmission and the minimum measured optical transmission. The data is not normalized for the length of cable tested because there was a mated pair included in the oven during testing which introduces other types of variables in addition to thermal related expansion and contraction of the cable components themselves.

Table 5: Summary of thermal induced optical transmission changes for all cable channels tested for DUT A, B & C.

DUT Cable	Channel of DUT	Maximum Transmission Δ within a cycle	Maximum Δ over entire test duration.
A	1	1.6 dB	1.8 dB
A	5	0.8 dB	1.3 dB
A	8	0.1 dB	1.4 dB
A	12	1.2 dB	1.4 dB
B	1	0.9 dB	1.2 dB
B	5	1.2 dB	1.9 dB
B	12	0.8 dB	1.1 dB
C	1	1.4 dB	1.6 dB
C	3	1.3 dB	1.3 dB
C	5	1.0 dB	1.2 dB
C	6	0.9 dB	1.6 dB
C	8	0.7 dB	1.0 dB
C	10	1.3 dB	1.4 dB
C	12	1.5 dB	1.6 dB

An example of the data summarized in table 5 is shown in Figure 13. In Figure 13 the collected data for DUT A channel 8 is presented. The data can not be scaled by the length of the cables that were tested due to the mated pair of MTP connectors also under test. The most significant factor here was how much of a total change in transmittance was observed as a result of thermally induced effects.

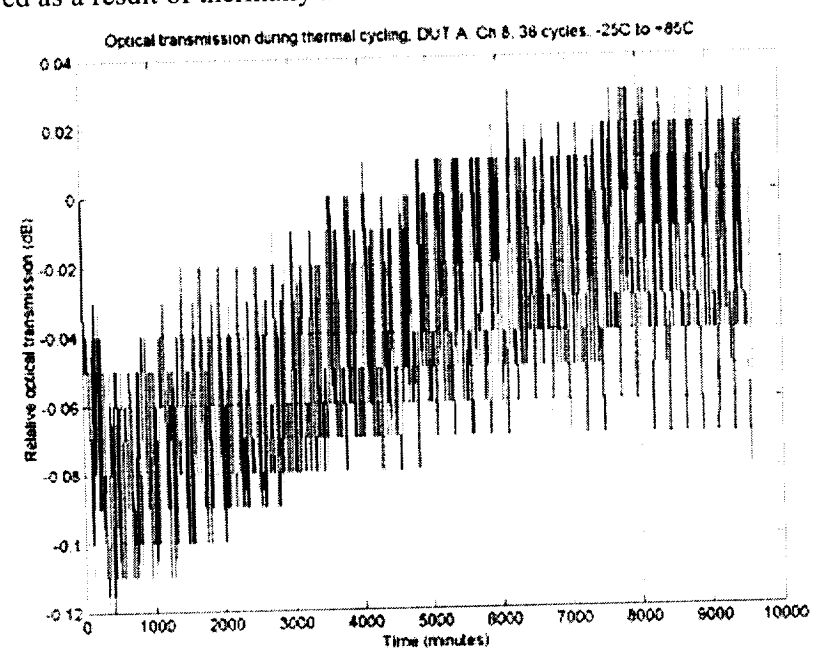


Figure 13: Thermally induced optical transmission changes for DUT A channel 8.

Again, the optical source power drift has been subtracted from the thermally induced optical transmittance changes. The average maximum transmittance change for DUT A using the channels tested was 1.48 dB, for DUT B using the three channels tested was 1.4 dB, and for DUT C for all seven channels tested was 1.39 dB. The performance of all three cables was similar in spite of the fact that DUT C was cycled 20 times less than DUT A and DUT B. A visual inspection of all mated pair end faces was conducted to verify the integrity of each channel of the optical fiber ends that were mated in the thermal chamber. All end faces passed visual inspection. No damage was noticed on all the recorded images. An example of the final visual inspection is presented in Figures 14 and 15. In Figure 14 the before and after testing visual inspection pictures are shown taken from the A side of the DUT A mated pair, for channel one. Figure 15 shows the before and after pictures for the B side of the DUT A mated pair for channel one.

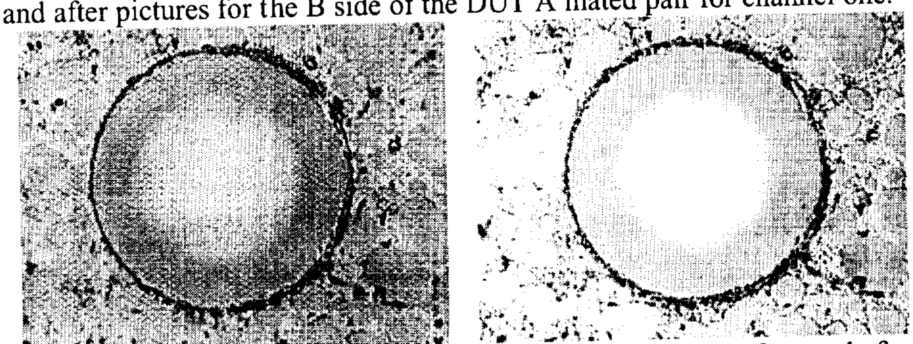


Figure 14: Cable set DUT A, connector side A on channel one before and after the vibration and thermal testing sequence.

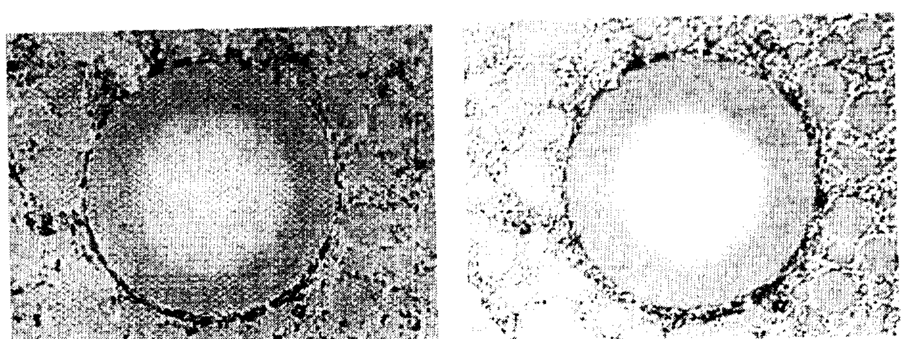


Figure 15: Cable set DUT A, connector side B on channel one before and after the vibration and thermal testing sequence.

All images collected, that total 72 images before (3 mated pairs= 6 endfaces*12 channels) and 72 images after, showed no damage as a result of the vibration and thermal sequence of testing. The complete collection of visual images is presented in Appendix A for cable set DUT A, Appendix B for cable set DUT B, and Appendix C for cable set DUT C.

Radiation Characterization:

Two of the cable assemblies were tested in a gamma radiation environment at room temperature 25 °C. DUT A and DUT B were tested for radiation effects at two different dose rates. The purpose of using DUT A and DUT B was to use the cables that had experienced the most thermal cycling or aging. Both DUT A and DUT B had been thermal cycled 38 times. The fiber inside of the cables was a 100/140/250 acrylate coated fiber that was not rated as "rad hard" and because of this is a commercial off the shelf product.

Table 6: Radiation Testing Parameters for DUT A and DUT B

Cable Set DUT	Radiation Dose Rate	Total Dose	Length*
A	4 rads/min	~ 62 Krads	5.24 m
B	27 rads/min	~ 403 Krads	5.24 m

* Length includes mated pair MTP interconnection

The dose rate and total dose for each test are summarized in Table 6. The cables were placed inside of lead box to eliminate external lower energy reflections and the dose rate inside of the box was measured and used for analysis (Table 6). Lead cables were used to connect the equipment outside of the Co60 chamber to the DUT cables. The input power to the DUT cables was attenuated such that the measured optical power at the output of the lead cable measured 0.88 microwatts CW. Measurements were made every minute and the test was started prior to opening the radiation gamma source shutter such that reference measurement could be made. The source was monitored throughout testing and source power drift was subtracted from the collected data such that it would not be included in the final analysis. A similar experimental set up was used as was used in the vibration and the thermal testing, however, an LED (RIFOCS 752L dual LED source) at 1300 nm was used as the source and an attenuator (JDS HA9 optical attenuator) was used between the output of the coupler (the input of the coupler was connected to the LED source) and the lead-in cable. The purpose was to limit the incoming optical signal to the DUT. The output lead-out cable connected the other end of the DUT to the detector equipment positioned outside of the radiation chamber. Again the HP8166 was used to detect the optical transmission signal. In both tests, channel twelve was tested. The objective of this testing was not to provide data that would necessarily would lead to an absolute model for the cable but that would provide an insight in to possible performance at room temperature. However, the data was used to provide a model that could be used to predict lower dose attenuation if all the assumptions made were correct.

Radiation characterization results

The testing for DUT A at 4 rads/minute was conducted for approximately 10 days and 18 hours. The test was continued after the radiation exposure was ceased, to gather additional recovery data. In Figure 16, the entire collected data set for DUT A during and just after radiation testing is plotted vs. time. At approximately 15489 minutes (~62 Krads) the gamma source shutter was closed, ending the radiation exposure (gamma source off). The data presented has the LED source variations subtracted from the data.

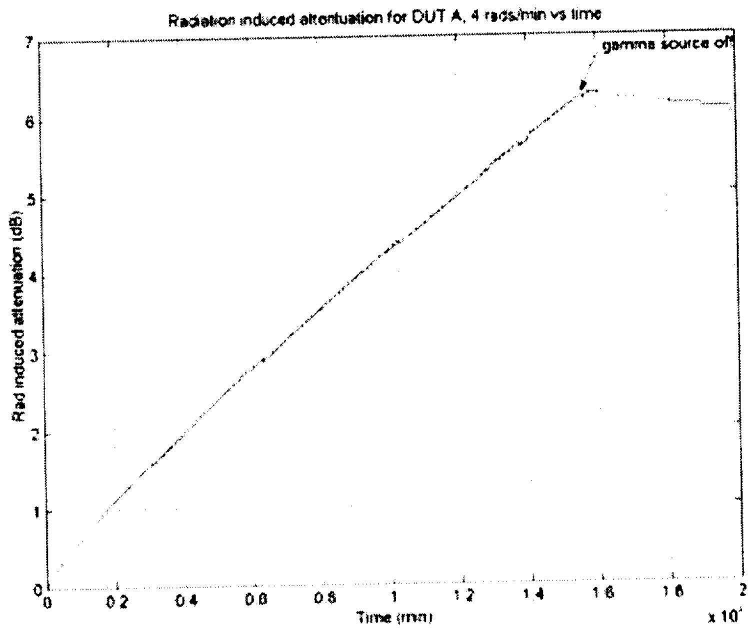


Figure 16: Radiation induced attenuation with recovery data for DUT A tested at 4 rads/min to a total of ~ 62 Krads,

The radiation induced attenuation for DUT A ends at 6.18 dB (15489 minutes) and over the next 3 days recovers to only 6 dB induced attenuation. The equation that describes the radiation induced attenuation during the exposure is

$$A(D)=8.9*10^{-4}D^{.8007}, \tag{1}$$

where A(D) is the radiation induced attenuation and D is the total dose. The form of this equation is chosen to fit the model developed by Friebele et al [5] and used in previous reports to model the radiation induced attenuation of germanium doped fiber [3]. Figure 17 shows the data along with the curve fit for the exposure data, equation 1. The red plot is the graph of equation 1 and the blue plot is the actual radiation data during exposure of DUT A.

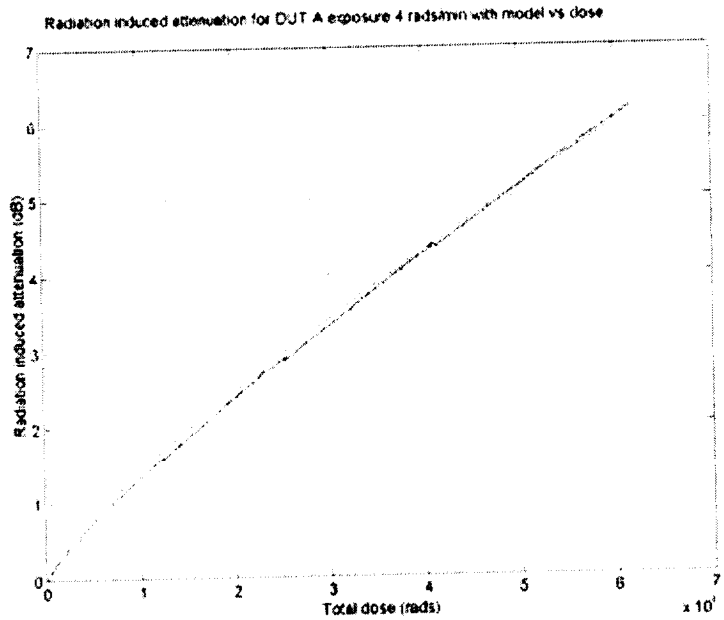


Figure 17: Radiation induced attenuation for DUT A during radiation exposure of 4 rads/min (blue) and the results of graphing equation 1 (red).

The data for the radiation exposure of DUT B possessing the same configuration and fiber from the same lot as DUT A is presented in Figure 18.

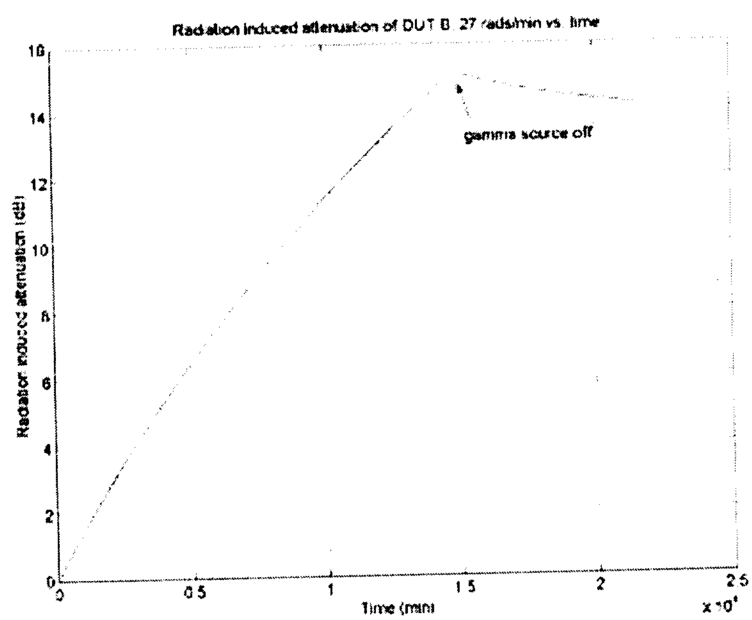


Figure 18: Radiation induced attenuation of DUT B with recovery data, exposed at 27 rads/min vs. time, to a total dose of 403 Krads.

For the 27 rads/min dose rate exposure of this cable the highest attenuation at 403 Krads was measured as 15.18 dB. The cable recovery data shows that after another 4.6 days, the attenuation drops to 14.16 dB. Based on the Friebele model and using equation 1 as a basis for the model at 27 rads/min, the equation for attenuation as a result of radiation exposure is

$$A(D) = 5.0*10^{-4}\ D^{.8007} \qquad (2)$$

Where again, A(D) is radiation induced attention dependent on total dose in rads and D is total dose in rads. The model and actual data for the 27 rads/min test is presented in Figure 19.

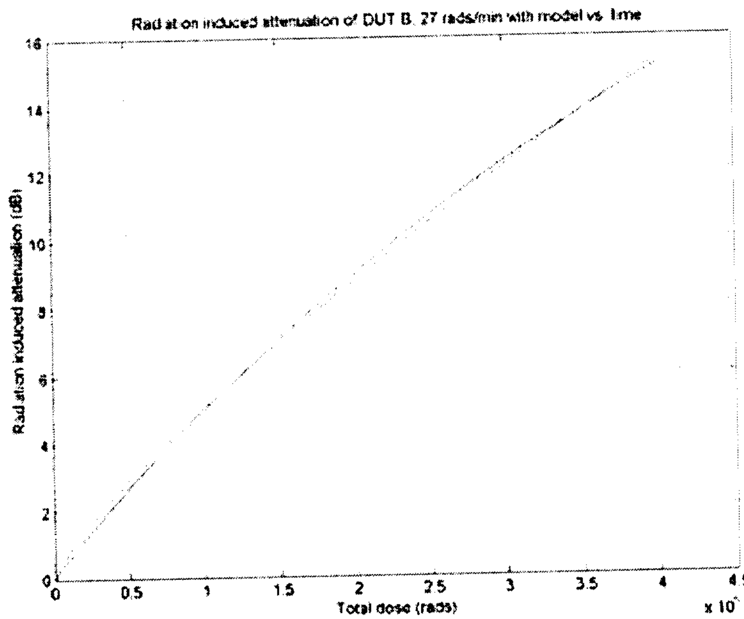


Figure 19: Radiation induced attenuation for DUT B at 27 rads/min during gamma exposure (blue) and the curve fit plot of equation 2 (red).

Based upon the model equations no general model can be derived without making new assumptions about the constant Co. The Friebele model takes the form:

$$A(D) = Co\ \phi^{1-f}\ D^{f} \qquad (3)$$

Where ϕ is the dose rate, D is the total dose, f is less than 1, and Co is the constant [5]. Two sets of data are necessary to determine which f and Co are appropriate to use the equation for extrapolation to other dose rates. The equation is used to describe the radiation induced attenuation on typical germanium doped optical fiber. It has not been specified for cable, which is what was tested here. The value for f was determined by analysis of the two data sets and under the assumption that f is the same for both data sets, than the only variable left undetermined is Co. Using equation 1 where the dose rate was 4 rads/min Co = $6.75*10^{-4}$, and using equation 2 where the dose rate was 27 rads/min, Co = $2.59*10^{-4}$. The constants would need to be the same in order to write a general extrapolation expression for other dose rates. Perhaps the difference in constants is related to the cabling used on top of the fiber or other factors when setting up the arrangement of the cable in the chamber. The cable was not spooled tightly the way fiber is usually tested and because only one channel was tested on each cable of the twelve optical fibers available, the way the cable was lying near the source could have created variations in the normal response. However, those would be normal variations that would occur in an actual space application where cable is not spooled when installed on the spacecraft.

If we assume that the cabling configuration was the largest contributing factor and did affect the constant such that it became dependent on the dose rate, than a relationship using both data sets and a linear assumption (since there are only two data sets) can be used to make a model for Co at other dose rates.

Solving for Co(ϕ) using both data sets the expression for the constant is

$$Co=-1.8*10^{-5}\,\phi + 7.47*10^{-4} \qquad (4)$$

Where ϕ is the dose rate and Co becomes the new constant in equation 3. This equation is graphed in Figure 20. Using this plot and from equation 4, as the dose rate becomes very small or less than 1 rad/min which is typical of space flight background radiation, Co becomes $7.47*10^{-4}$ therefore making the dependence on dose rate for the constant a non issue.

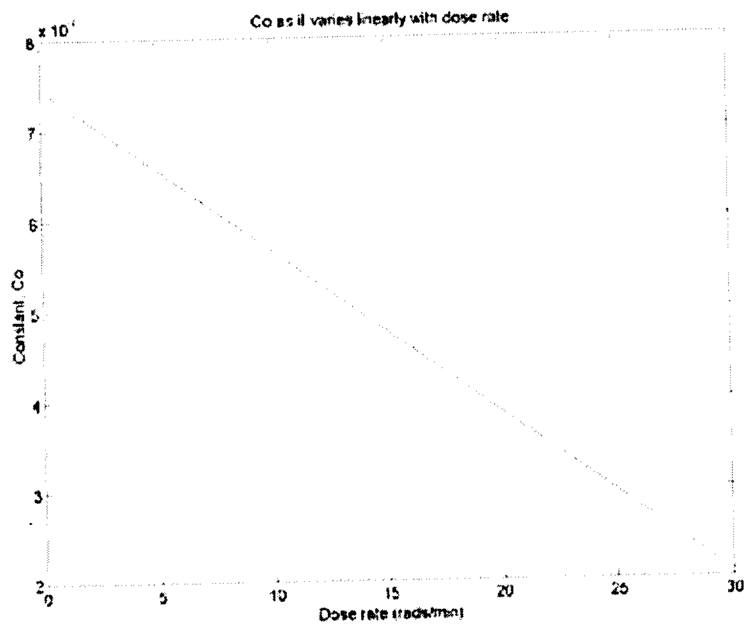


Figure 20: The constant Co as it varies linearly with dose rate based on equation 4.

Using the assumption that most space flight environments that will use the commercial twelve fiber ribbon cable will have back ground radiation at levels less than l rad/min, the expression for radiation induced attenuation can be described as:

$$A(D) = 7.47*10^{-4}\,\phi^{.1993}\,D^{.8007} \qquad (5)$$

Again, this model is only valid at very low dose rates using all the assumptions described previously.

Table 7: Radiation induced attenuation summary of actual and extrapolated data

Cable Set	Dose Rate	Total Dose	Attenuation
DUT A	4 rads/min	62 Krads	6.18 dB
DUT B	27 rads/min	403 Krads	15.18 dB
Extrapolated	.1 rads/min	100 Krads	4.75 dB
Extrapolated	.1 rads/min	10 Krads	.75 dB

Table 7 summarizes the final radiation induced attenuation for DUT A and DUT B and also gives the results of extrapolation to a 0.1 rads/min dose rate for radiation induced attenuation. These attenuation values are based on the entire 5.24 m of cable in the chamber and are not represented as attenuation/m as is usually the case. In this case the purpose was to qualify a mated cable pair such that would be used between two instruments in a space flight application. Figure 21 is the entire extrapolated data set for 0.1 rads/min up to 100Krads.

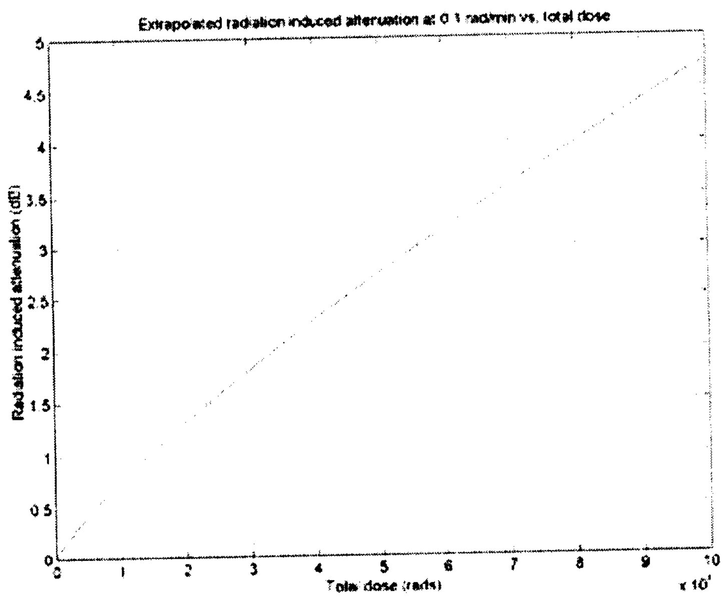


Figure 21: Extrapolated values for radiation induced attenuation using 0.1 rads/min for a total dose of 100 Krads.

Conclusions:

The twelve channel optical fiber (with 100/140/250 optical fiber) ribbon cable (W.L. Gore) assembly with USConec MTP array connector was characterized for a space flight environment using the environmental specifications for Goddard Mission GLAST. Three cable sets were tested which consisted of a mated pair of MTP connectors. The length of the mated pair was 5.24 m.

During vibration testing one channel (channel six) was optically monitored for "dynamic" transients at a 25 microsec sampling rate. Three tests were conducted per cable, one in each axis (x,y,&z) direction. There were nine tests conducted total (3 tests per cable, 3 cables). From the collected data of the nine tests conducted, six data sets showed loss transients less than 0.1 dB, one showed loss transients less than 0.2 dB, and the other showed loss transients less than 1.2 dB.

During the "static" testing (monitoring for slow changes in optical performance) of the cables, six channels on each cable assembly were optically monitored for losses as a result of vibration. The largest static losses registered were from DUT C during Y axis vibration testing at 0.4 dB.

Thermal cycling or accelerated aging tests were conducted on all three cable test sets. DUT A and DUT B were tested using 38 cycles, and 18 cycles were used for DUT C. Four channels of DUT A were optically monitored for shifts in the transmission, three channels of DUT B were monitored and seven channels of DUT C were monitored. The collected data shows that the largest overall transmission change for all the channels tested was registered from DUT B at 1.9 dB. The largest change within a cycle (thermally induced optical cycle) was recorded from DUT A channel 1. The average measured losses were 1.48 dB for DUT A, 1.4 dB for DUT B, and 1.38 dB for DUT C.

Two of the cable test sets were exposed to gamma radiation. DUT A was tested at 4 rads/min to a total dose of 62 krads and was monitored optically throughout the testing. The largest recorded radiation induced attenuation was 6.18 dB for the entire 5.24 m length just before the radiation shutter was closed. DUT B was tested at 27 rads/min to a total dose of 403 rads/min and the final radiation induced attenuation measured before ceasing exposure was 15.18 dB. Using the extrapolation method for a dose rate of 0.1 rad/min the estimated radiation induced attenuation at 10Krads total dose would be .75 dB for the entire 5.24 m and 4.75 dB at 100 Krads.

After all testing was completed, visual inspection data was recorded and compared to visual inspection images taken prior to testing. No damage was detected. The complete visual inspection collection of images is presented in Appendix A, B and C corresponding to the letter designation of each cable test set.

It is evident that the cable assemblies did pass characterization with minimal losses and no damaged optical endfaces. The cable/connector assemblies have proven the ability to withstand the space flight environments used for this characterization.

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